

# The Possibility of Selected Surface Layer Modification of Nodular Iron Engine Parts by Laser Boronizing

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## Abstract

The influence of the laser boronizing on the surface layer of nodular iron was studied. The CO<sub>2</sub> molecular Trumpf laser TLF 2600t has been used. The obtained modified surface layer has been investigated by light and scanning electron microscopy, Auger Electron Spectroscopy, Vickers microhardness tester and surface roughness device. The aim of presented research was to define the influence of laser boronizing parameters on microstructure and properties of nodular iron surface layer. After laser boronizing surface layer of nodular iron contained three zones: melted-, transition- and hardened form solid state-one. Melted zone was characterized by fine-crystalline microstructure – as oppose to transition and hardened zones. Thickness of melted zone increased with increasing laser beam power density used during treatment. The Fe<sub>2</sub>B iron borides with characteristic polygonal shape have been observed in melted zone. Amount of boron in melted zone was enough to boride irons that could create. The higher laser beam power density was applied, the smaller average boron amount was (as a result of the larger melted zone size). High microhardness of melted zone was achieved. Microhardness of the melted zone depended on boron concentration. Boron concentration in melted zone increased from 7 to 17%, causing increment of microhardness from about 1200 HV0.1 to 1600 HV0.1. Influence of laser beam power density during laser boronizing on surface profile parameters of nodular iron was also found, that is, the higher the laser beam density was, the larger the surface roughness was. The research carried out stated that the microstructure and properties of boronized surface layer could be controlled by laser treatment parameters. Useful correlations among laser treatment parameter, modified zone size, modified zone microhardness, amount of implementing alloying element in melted zone and roughness surface parameter have been observed and described, which has significant importance in nodular iron surface layer designing by laser treatment.

## Keywords

*Laser Alloying; Boron; Nodular Iron; Microstructure*

## Introduction

Nodular irons commonly used in practice because of

their good mechanical properties which approach that to cast steel and even some of steels. are characterized by good castability and machinability. Therefore, nodular iron with a number applications in automobile industry has been used for parts of engines and machine components such as crankshafts, camshafts, cylinder liners, gears etc. Some parts of those elements are exposed to intensive abrasive wear and corrosion during their work. Therefore, appropriate properties of surface layer are necessary.

Lasers have been applied in surface engineering. Laser heat treatment provides possibility of selected modification of surface layer, meaning that this treatment makes possible to change the microstructure and properties of very localized surface layer regions. According to the result of investigations concerning nodular iron laser treatment, the microhardness of melted zone is 3-4 times higher than that of bulk material. Conditions for microstructure modification in this case are totally different from conventional hardening methods. A microstructure similar to the one of hardened white cast iron is formatted in surface region due to high speed of melting and solidification during laser treatment. Additionally, melted zone has been found very fine-crystalline.

High microhardness (and corrosion resistance, as well) can be additionally increased by implementation during laser treatment in which appropriate alloying element creates hard and corrosive resistible phases. Such an element could be boron. One of common surface layer modifications that uses this element is chemical-heat treatment. Surface layers created by diffusion boronizing are characterized, first of all, by high microhardness and heat-proof corrosion resistance; however, on the other hand, textured, saw-tooth, usually two-phase structure with brittle FeB iron boride limits application of diffusion boronizing.

Moreover in cast irons diffusion boronizing case discontinuous graphite zone is created under borides layer. This fact additionally increases possibility of cracking and ripping borides layers off. By applying laser boronizing of nodular iron surface, it is possible to achieve hard, corrosive-resistant layers without some undesirable characteristics typical for the cast irons diffusive boronizing, mentioned above. Positive effects with boron implemented by laser treatment have been already gotten, for example, in bearing steel and nodular iron cases. Moreover, it was proved that nodular iron boronized in this way is characterized by better wear resistance than the untreated one. So these positive results of previous investigations make reasonable to continue research concerning nodular iron laser boronizing.

The aim of presented research is to evaluate the laser treatment parameters during laser boronizing having influence on surface layer of nodular iron. The influence of laser beam power density on modified zone size, modified zone microhardness, amount of implementing alloying element in melted zone and roughness surface parameters are particularly important aspects to be defined in this investigation. The knowledge about such correlations is especially required for laser treatment parameters designing for different nodular iron machine parts.

## Experimental Method

Nodular iron 500-7 was chosen as the test material. The chemical compositions of investigated iron are presented in table 1.

TABLE 1 THE CHEMICAL COMPOSITION OF THE 500-7 NODULAR IRON

Element	C	Si	Mg	Mn	Cr	P	S	Cu
wt. %	3.82	2.53	0.06	0.33	0.02	0.042	0.013	0.257

Laser treatment was performed with the molecular CO<sub>2</sub> continuous Triumph laser type TLF 2600t at 2.6-kW output power and TEM<sub>01</sub> mode. The covering paste consists of an alloying substance and water glass. Amorphous boron was used as an alloying substance. Thickness of covering paste on each sample was approx 40μm. Simultaneously, the melted covering material and thin layer of the base material form a layer (enriched with boron) and are characterized by different chemical composition, microstructure and properties from the base material (nodular iron) and the covering material (paste with amorphous boron).

The laser beam power (P) in the range from 300 to 1900 W was used. Constant laser beam diameter (d = 4 mm) and laser beam interaction time (t = 0,5 s) were applied. Consequently, laser beam power density (E) in the range from 40 to 150 W/mm<sup>2</sup> was achieved.

Results of the laser treatment were analyzed by means of light microscope and scanning electron microscope (melted zone geometry dimensions evaluation and microstructure study), Vickers microhardness tester (melted zone microhardness measurement), Auger Electron Spectroscopy (chemical composition analysis), surface roughness device (surface roughness parameters measurement). The scheme of the treated samples is presented in fig 1.

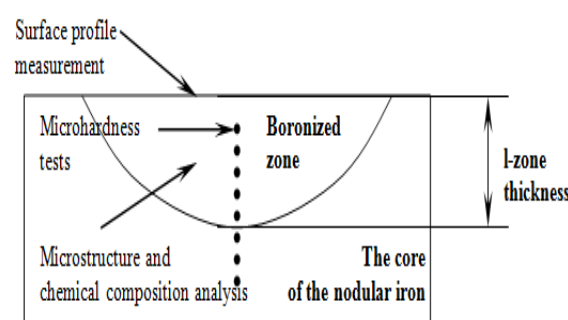


FIG. 1 THE SCHEME OF THE SAMPLE AFTER LASER BORONIZING

## Results and Discussion

After laser boronizing of nodular iron, three zones could be distinguished: melted (boronized), transition and hardened from solid state (fig. 2). The melted zone is the first one from the surface, visible as a bright area. The transition zone is the thinner one—between melted and hardened from solid state zones and it contains melted and non-melted phases during laser treatment. This zone contains graphite nodules in double shells (characteristic only for nodular iron laser treatment) made of ledeburite and martensite in a ferrite-martensite matrix (fig. 2). It is the result of carbon diffusion from graphite nodules into austenite during laser heating, causing increasing concentration of carbon in the matrix surrounding the nodules. Thus, the temperature of melting point is lowered locally. Consequently, locally melting area around graphite could occur. After rapid cooling, ledeburite around graphite nodule is formed. Next to ledeburite shell from enriched austenite with carbon martensite shell is formed. Because of the presence of transition zone, good bond between melted and non-melted part of surface layer is expected.

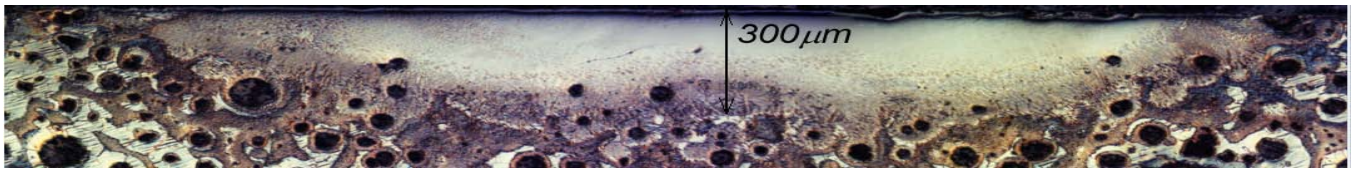


FIG. 2 THE CROSS SECTION OF THE LASER BORONIZED SURFACE LAYER NODULAR IRON. LIGHT MICROSCOPE. ETCHED WITH NITRIC ACID

In the fig. 2 under transition zone, zone hardened from the solid state is visible. The hardened zone is characterized by graphite nodule in martensite shell in ferrite-martensite matrix. The martensite shell formation is analogical as it takes place in transition zone. During laser heating carbon diffusion from graphite nodules into austenite causes increasing carbon concentration in the matrix (but the temperature of melting-point is not exceeded in this zone). High enough cooling rate caused martensite shell formation surrounding graphite nodules. Austenite with lower carbon concentration transforms back into ferrite. It was noticed that martensite shells in transition zone vicinity are thicker than those in the core vicinity.

Although transition zone and zone hardened from the solid state are significant because of their strengthener of the whole created surface layer, the essential importance in machine parts exploitation is determined by melted zone because of its unique microstructure and properties. of the appearing of melted zone and its size are dependent on laser beam power density (fig. 3). The higher the laser beam power density was, the larger the thickness of melted zone was. Only in case of one variant of performed treatment (for laser beam power density of 40 W/mm<sup>2</sup>) melted zone did not form. This value of laser beam power density was not enough to melt the surface layer. Nevertheless, during this variant of treatment, temperature generated in surface layer was enough to create austenite zone. Consequently, hardened zone from solid state appeared.

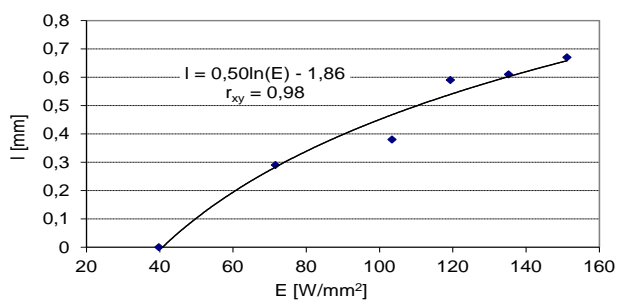


FIG. 3 THE INFLUENCE OF LASER BEAM POWER DENSITY (E) ON MELTED ZONE THICKNESS (l) OF LASER BORONIZED NODULAR IRON

Contrary to the transition and hardened zones, melted

(boronized) zone is characterized by fine-crystalline microstructure (fig. 4). However, some undiluted graphite nodules during laser treatment zone can be observed occasionally (fig. 2, 5). The characteristic, polygonal shape of boride irons created by this kind of treatment could be distinguished in melted zone as well (fig. 5). Such shapes, typical for Fe<sub>2</sub>B iron borides, have been found in previous research with respect to laser boronizing and plasma boronizing.

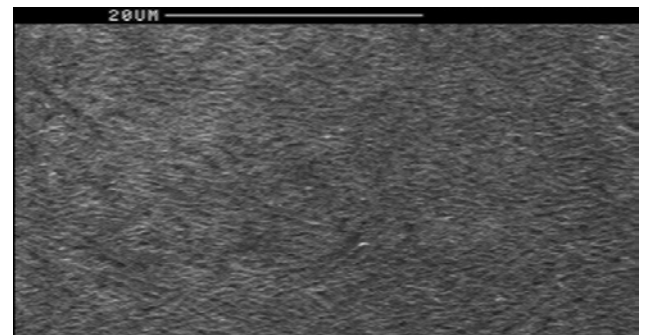
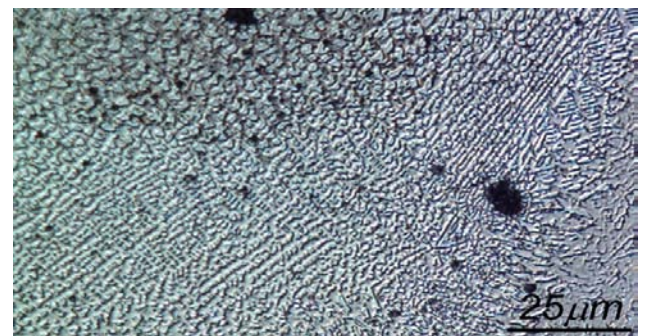
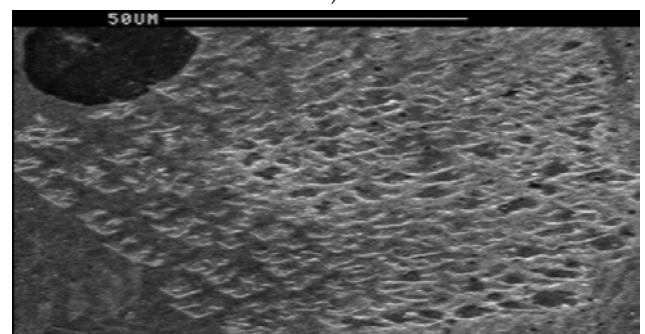


FIG. 4 PART OF MELTED ZONE IN NODULAR IRON SURFACE AFTER LASER BORONIZING. SCANNING ELECTRON MICROSCOPE. ETCHED WITH NITRIC ACID



A)



B)

FIG. 5 BORIDE IRONS IN MELTED ZONE IN LASER BORONIZED NODULAR IRON SURFACE LAYER OBSERVED BY LIGHT MICROSCOPE (A) AND SCANNING ELECTRON MICROSCOPE (B). ETCHED WITH NITRIC ACID.

AES research proved that the amount of boron in melted zone is enough to create hypoeutectic or eutectic microstructure. It was noticed that the average boron amount in achieved zones is in the range from 7 to 17% at. (fig. 6). The analysis of chemical composition revealed that the higher the laser beam power density is applied, the smaller the boron amount in melted zone is (fig. 6); is due to of the lager size of melted zone. The amount of boron is 4- higher than iron when thickness of melted zone is approx. 0,3-0,4 mm (favoring eutectic microstructure creation) and it is 9-times lower when thickness is 0,6-0,7 mm (favoring hypoeutectic microstructure creation) (fig. 7).

Such fine microstructure, with hard boride irons, generated high microhardness of the melted zone. Microhardness measurements stated that melted zone is characterized by approx 5/7times higher microhardness than untreated material. Microhardness of some areas of melted zone reached even 1800 HV0.1.

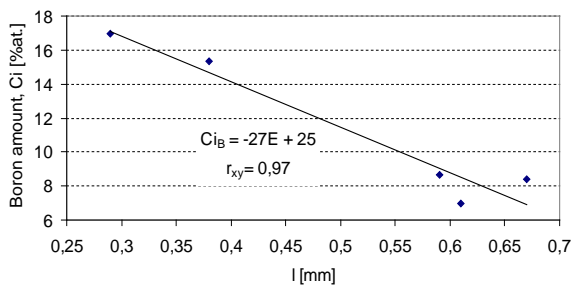


FIG. 6 THE DEPENDENCE BETWEEN BORON AMOUNT IN MELTED ZONE AND MELTED ZONE THICKNESS (l) OF NODULAR IRON AFTER LASER BORONIZING

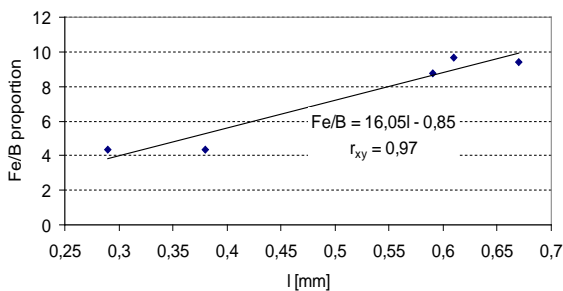


FIG. 7 THE PROPORTION OF Fe/B IN MELTED ZONES WITH DIFFERENT THICKNESSES (THE INFLUENCE OF LASER BEAM POWER DENSITY (E) ON MELTED ZONE THICKNESS (l) OF LASER BORONIZED NODULAR IRON

The influence of laser treatment parameters on microhardness could be observed (fig.8). It also might be noticed, that the thinner melted zone is (fig. 3), the higher average microhardness could be expected. It is due to higher concentration of boron in melted zone (fig.9). Linear correlation between  $C_{iB}$  boron amount and HV0.1 microhardness of melted zone was found

as the best one. It could be stated that the microhardness and size of melted zone could be controlled possibly using appropriate laser treatment parameters during boronizing.

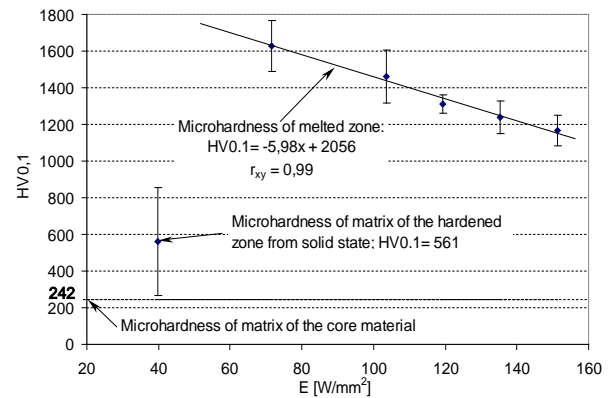


FIG. 8 THE AVERAGE MICROHARDNESS OF NODULAR IRON SURFACE LAYER AFTER LASER BORONIZING ACHIEVED WITH DIFFERENT LASER BEAM POWER DENSITIES

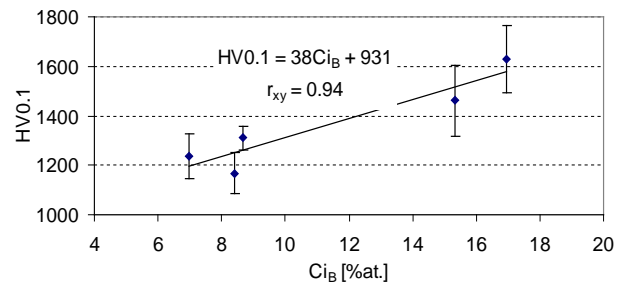


FIG. 9 THE INFLUENCE OF BORON AMOUNT IN MELTED ZONE ON ITS MICROHARDNESS OF NODULAR IRON AFTER LASER BORONIZING

Except microstructure and microhardness of surface layer, roughness parameters are also determined by laser treatment parameters. The surface profiles are presented in fig. 10, 11 and 12. It could be noticed that laser heating without remelting surface layer has not changed the surface profile (fig. 10, 11), as oppose to laser treatment with remelting (fig. 12). The higher the laser beam density is, the larger the surface roughness parameters ( $R_a$ ,  $R_z$ ) are (fig. 13). Therefore, the superfinish mechanical treatment after laser treatment with remelting need to be always planned (as oppose to laser treatment without remelting). Moreover, the higher the laser beam density applied is, the thicker the surface layer to be removed by mechanical treatment is.

It could be stated that lower laser beam power densities (70/110W/mm<sup>2</sup>) are supposed to be more appropriate than higher ones (>110 W/mm<sup>2</sup>) to be used in machine parts surface modification. Higher microhardness of surface layer and smaller changes in surface profile could be achieved in case of using lower laser beam densities. Additional advantage of

using lower beam power densities is less intensive heating of the whole treated machine part. It is worthy

to emphasize the economical aspect of less power consumption (when lower laser beam power is used).

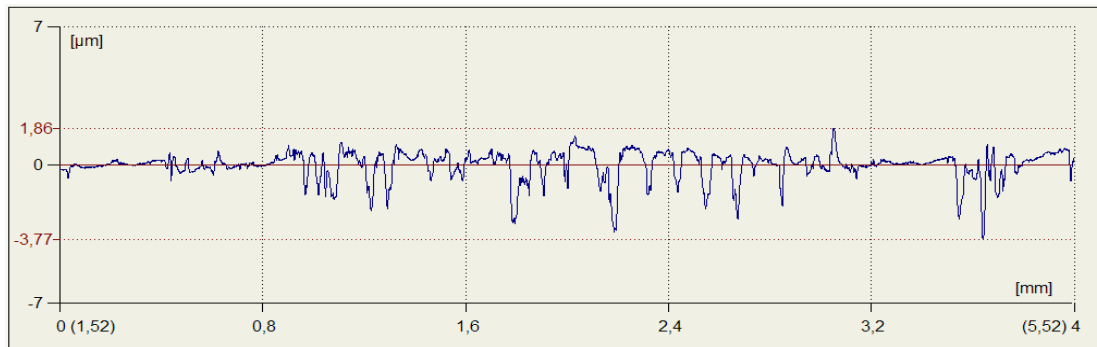


FIG. 10 THE SURFACE PROFILE OF UNTREATED NODULAR IRON



FIG. 11 THE SURFACE PROFILE OF NODULAR IRON AFTER LASER TREATMENT WITH LASER BEAM POWER DENSITY OF 40 W/mm<sup>2</sup>

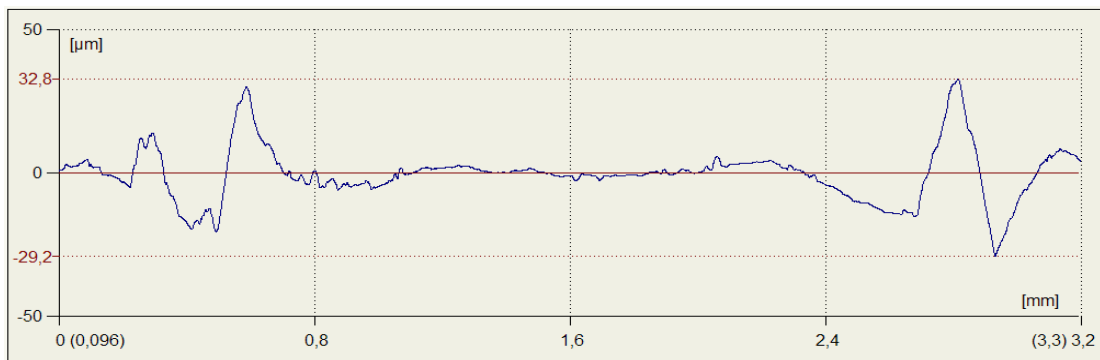


FIG. 12 THE SURFACE PROFILE OF NODULAR IRON AFTER LASER TREATMENT WITH LASER BEAM POWER DENSITY OF 150 W/mm<sup>2</sup>

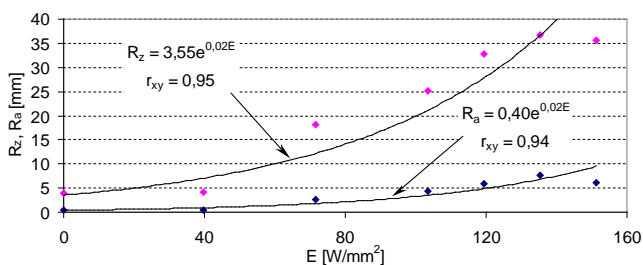


FIG. 13 THE INFLUENCE OF LASER BEAM POWER DENSITY (E) ON SURFACE PROFILE PARAMETERS ( $R_a$ ,  $R_z$ ) ACHIEVED AFTER LASER TREATMENT OF NODULAR IRON

## Conculsion

The following conclusions can be drawn from the research.

Surface layer of nodular iron after laser boronizing

contains three different zones: melted-, transition- and hardened from the solide state-one. As a result of the presence of transition zone, good bond between melted and hardened zone is expected. The transition zone and zone hardened from the solide state with hardened form are significant because of their strengthener of the whole created surface layer.

Melted zone is characterized by fine-crystalline microstructure—as opposed to transition and hardened zone. Thickness of melted zone increased with increasing laser beam power density. The Fe<sub>2</sub>B iron borides with characteristic of polygonal shape have been observed in melted zone after laser boronizing.

High microhardness of melted zone (even 7-times higher than microhardness of untreated material) was

achieved. The higher the amount of boron detected was, the higher the microhardness of melted zone noticed was. Boron concentration in melted zone increased from 7 to 17% causing increase of microhardness from about 1200 HV0.1 to 1600 HV0.1. The lower the laser beam power density applied was, the higher the average boron amount was (as a result of the smaller melted zone size).

The influence of laser beam power density during laser boronizing on surface profile parameters of nodular iron was also found. The higher the laser beam density applied was, the higher the values of surface roughness parameters were. Increase of surface roughness parameters causes superfinish mechanical treatment of machine parts after laser treatment with remelting.

The implemented research stated that it is possible to create boronized surface layer of nodular iron by laser treatment, and good wear resistance of machine parts treated by laser boronizing could be expected. The microstructure and properties of surface layer could be controlled by laser treatment parameters. Useful correlations among laser treatment parameter, modified zone size, modified zone microhardness, amount of implementing alloying element in melted zone and roughness surface parameter have been found and described. Those correlations have significant importance in nodular iron surface layer designing by laser treatment.

Laser beam power densities in range of: 70÷110 W/mm<sup>2</sup> are supposed to be appropriate to be used in machine parts surface modification because of high microhardness achieved in surface layer (approx. 1500 HV0.1) and relatively moderate changes in surface roughness. Lower beam power densities cause less intensive heating of the whole treated machine part

and less power consumption during treatment.

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**Marta Paczkowska** received the Ph.D. degree in Surface Engineering from Poznan University of Technology, Poznan, Poland, in 2008. She is currently assistant professor in the Faculty of Machines and Transportation in Poznan University of Technology. Her research interests include material engineering, surface engineering, surface treatment and laser modification. She has published many scientific papers in refereed journals and conference proceedings. Dr Paczkowska is a member of Polish Academy of Science.